Journal of Integrated and Advanced Engineering (JIAE)
Vol. 4, No. 2, September 2024: 87-102
http://asasijournal.id/index.php/jiae
http://doi.org/10.51662/jiae.v4i2.126

Marshall characteristics and durability of hot rolled sheet–wearing course using rubber asphalt

Elsa Eka Putri[1,2]*, Nilda Tri Putri[1], Farid Alqadri[2], Andriani[2], Yosritzal[2],
[1]Professional Engineer Program, School of Postgraduate, Universitas Andalas, Indonesia
[2]Department of Civil Engineering, Faculty of Engineering, Universitas Andalas, Indonesia

Abstract
Many road damages are caused by road construction that does not follow standards, so evaluating road conditions and choosing the appropriate asphalt for each state is essential. So, in this study, the asphalt mixture was modified using rubber asphalt with a percentage of rubber of 7% in the Hot Rolled Sheet-Wearing Course (HRS-WC). This study aimed to identify the effect of rubber asphalt on Marshall's characteristics and durability in HRS-WC. The method in this study is the Marshall Test and the calculation of the durability index on the test specimen with an immersion time of 0.5, 24, 72, and 168 hours at a temperature of 60°C. From the test results, the Optimum Asphalt Content (OAC) value of the rubber asphalt mixture was 7.13% with Marshall characteristic values of 4078.686 kg, flow 3.266 mm, MQ 1270.676 kg/mm, VMA 21.487%, VFB 71.983%, and VIM 6.062%. From the durability test results, the Residual Strength Index (RSI) value entered the specification only until the 24-hour immersion time with a value of 94.891%. The First Durability Index (FDI) and Second Durability Index (SDI) values are positive, where the mixture loses strength with increasing immersion time. It can be concluded that using rubber asphalt in HRS-WC is good enough for pavement because almost all Marshall characteristics were included in the specifications used. The stability value in the rubber asphalt mixture is higher than that of the pen—60/70 asphalt mixture. However, the level of durability of the rubber asphalt mixture is relatively low because it can only last up to 24 hours of immersion. Therefore, HRS-WC using rubber asphalt is unsuitable in areas with low groundwater levels or areas that often flood.

Keywords:
Durability;
Hot Rolled Sheet – Wearing Course;
Marshall;
Rubber Asphalt;

Article History:
Received: 29 November 2023
Revised: 5 May 2024
Accepted: 19 October 2024
Published: 24 October 2024

Corresponding Author:
Elsa Eka Putri,
Department of Civil Engineering, Faculty of Engineering, Universitas Andalas, Indonesia
Email: elsaeka@eng.unand.ac.id

INTRODUCTION

Road damage is a common problem in Indonesia and can have negative impacts on the economy and safety of the community [1]. Damaged roads can cause accidents and hinder the movement of people and goods, leading to increased transportation costs and reduced productivity [1]. Road damage can be caused by various factors, including overloading vehicles, natural disasters, and poor road construction practices [2].

Improving the quality of roads is important to ensure that road construction is carried out according to established standards [3]. The Indonesian government has implemented various measures to improve road infrastructure in the country, including constructing new toll roads and repairing existing roads [4]. In addition, the use of sustainable road construction practices, such as green road construction, can help reduce the environmental impact of road construction and improve the durability of roads [5].

Road pavements in Indonesia generally use bending pavements. One type of surface layer commonly used is the Hot Rolled Sheet-Wearing Course (HRS-WC) because it has elastic and durable properties. This is due to the gradation of the HRS-WC mixture gap, which has an air void large enough to absorb a large amount of asphalt (7-8%) without excess asphalt (bleeding). In addition, HRS-WC is also easy to obtain, so the resulting layer has high water and air resistance [6]. The aggregates used in this study are aggregates from CV. Bakri Mandiri, Padang Pariaman quarry.

Durability is an important property of the asphalt mixture that ensures the quality of roads and their longevity [7, 8, 9]. It measures how well the asphalt mixture can resist factors such as changes in the binder, disintegration of the aggregate, and stripping of the binder films from the aggregate [10][11]. These factors can result from weather, traffic, or a combination of both [12].

Various measures can be taken to improve the durability of asphalt mixtures, such as using high-quality aggregates, optimizing the asphalt binder content, and ensuring proper compaction during construction [13]. In addition, the use of sustainable road construction practices, such as green road construction, can help reduce the environmental impact of road construction and improve the durability of roads [14].

The ability of asphalt mixture to withstand various environmental conditions is the main factor in determining service life and road performance [15]. Using non-standard asphalt often leads to premature deterioration and decreases the service life of the road. This can lead to cracks, surface damage, or structural damage to the road. Therefore, it is essential to evaluate the condition of the road and choose the type of asphalt suitable for each condition.

Modification technology is needed for the asphalt mixture to improve the quality of highway pavement construction and to ensure good material selection [7]. Asphalt mixture modification technology can improve the performance of asphalt mixtures and enhance their durability, deformation resistance, and cracking resistance [16].

Various types of asphalt mixture modification technologies can be used in highway pavement construction, such as polymers, concentrated rubber, graphene, and polyurethane [7,16,17,18]. These technologies can be used to modify the properties of asphalt mixtures and improve their performance under different conditions.

Rubber asphalt is a type of asphalt that has been modified by adding natural rubber as an additional material. The addition of rubber to asphalt can improve its performance and durability, as well as reduce its environmental impact. Rubber asphalt can be produced using two types of rubber: liquid rubber (latex) and solid rubber (crumb rubber) [16].

Using crumb rubber in asphalt modification has enhanced the performance of asphalt mixes compared to conventional asphalt types [16]. Crumb rubber is obtained from recycled tires and can be used to modify the properties of asphalt mixtures, such as their resistance to deformation and cracking [16].

Adding rubber to asphalt can improve its properties, such as softness point, elasticity, and stickiness, making it more durable. The use of crumb rubber in asphalt modification has been shown to enhance the performance of asphalt mixes compared to conventional asphalt types [16]. Crumb rubber is obtained from recycled tires and can be used to modify the properties of asphalt mixtures, such as their resistance to deformation and cracking [16]. The asphalt used in this study was SIR 20 rubber with a percentage of 7% rubber from PT. Bumi Mulia Perkasa, Jakarta.

The HRS-WC is resistant to cracking, but damage occurs in the form of deformation, such as the emergence of unavoidable grooves. Rubber asphalt is expected to make the pavement surface more durable and resistant to cracks due to excessive deflection. This study aimed to identify rubber asphalt's effect on Marshall's characteristics and durability of Hot Rolled Sheet–Wearing Course (HRS-WC).

METHOD

The research was conducted according to methods and stages based on predetermined standards to obtain research results on the effect of rubber asphalt on Marshall characteristics and durability of Hot Rolled Sheet–Wearing Course (HRS-WC). The test was conducted at the Transportation and Highway Pavement Laboratory, Faculty of Engineering, Universitas Andalas, Padang. Research is carried out by conducting analytical and experimental studies, as shown in Figure 1. Data was collected by conducting the Marshall test and durability test.

After the literature study, it further prepares tools and materials for aggregate and rubber asphalt inspection. Aggregate and rubber asphalt are inspected to test the quality of the material used until it meets predetermined specifications. After the aggregate and rubber asphalt assessment, the aggregate content and Theoretical Asphalt Content (TAC) were determined. The method used to obtain aggregate levels is the mid-section point method, and the method used to get theoretical asphalt levels is the Department of Settlement and Regional Infrastructure (Depkimpraswil) 2002 method.

Test specimens can be manufactured by varying the asphalt content by reducing and adding the theoretical asphalt content value by 0.5%. The asphalt content used in this test is five types of asphalt content, and each asphalt grade is made of three samples. Marshall testing is carried out after obtaining theoretical asphalt grade values. The values obtained in the Marshall Test are entered into the Marshall table and then determined as the Optimum Asphalt Content (OAC) value. OAC is obtained by processing the data in the Marshall table and entering the results into a typical graph. Taking the asphalt content that enters the Marshall characteristics specification and calculating the average value based on the most data entered into the specification.

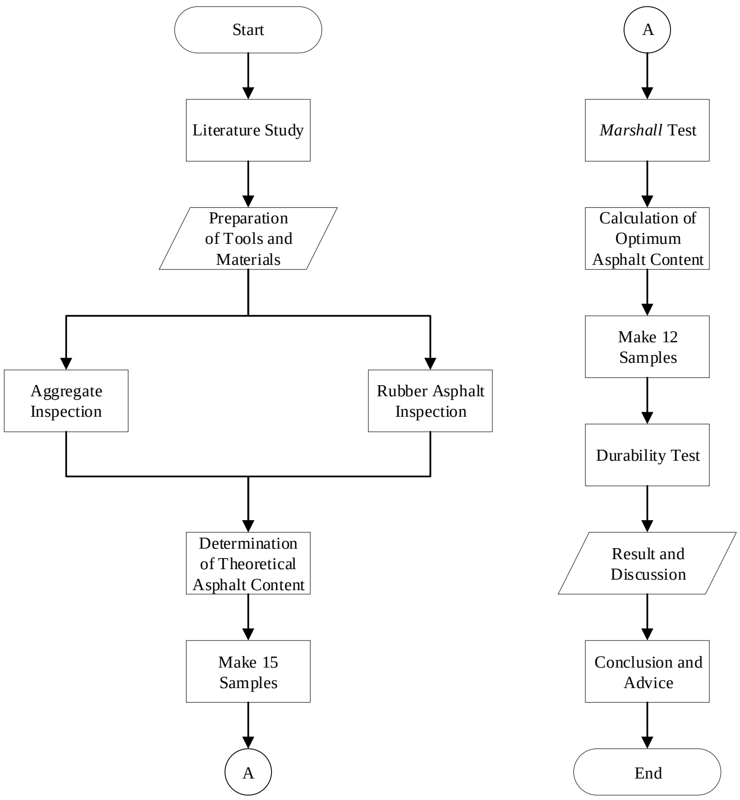

Figure 1. Research Flowchart

Furthermore, the manufacture of test specimens for durability testing was carried out with as many as 12 samples for the entire immersion time, where the asphalt content used was the optimum asphalt content. Durability testing is carried out by determining the effect of the variation in immersion time at a temperature of 60ºC. The variation of immersion time in this test is 0.5 hours, 24 hours, 72 hours, and 168 hours. After durability testing, the value of the Residual Strength Index (RSI), First Durability Index (FDI), and Second Durability Index (SDI) will be determined, and the durability value will be determined through the durability curve. After the test is complete, analyze the results and discuss the test as well as the conclusions and suggestions from the tests that have been done.

RESULTS AND DISCUSSION

Properties of Aggregate

The results of the aggregate inspection can be seen in Table 1. Table 1 shows that the aggregate inspection results for all tests have met the specifications according to the Highways General Specifications (Bina Marga 2018 Revision 2) [6].

Properties of Asphalt

The results of the asphalt inspection can be seen in Table 2 and Table 3. Based on Table 2, it can be concluded that the results of rubber asphalt inspection for all tests have met the specifications according to the Circular Letter from Ministers of Public Works and Housing (Pd 07-2019-B) for specifications of hot paved mixtures with asphalt containing natural rubber [19].

Table 1. Aggregate Inspection Results

Types of Inspection	Unit	Value	Testing Standards	Specifications
Coarse Aggregate			SNI 1969:2016	
Dry specific gravity	gr/cc	2.515		2.4 – 2.8
Surface Dry Saturated Specific Gravity	gr/cc	2.552		2.4 – 2.8
Apparent Specific Gravity	gr/cc	2.613		-
Absorption	%	1.490		Max 3%
The specific gravity of Aggregate	gr/cc	2.515		2.4 – 2.8
Fine Aggregate			SNI 1970:2008	
Dry specific gravity	gr/cc	2.570		2.5 – 2.7
Surface Dry Saturated Specific Gravity	gr/cc	2.613		2.5 – 2.7
Apparent Specific Gravity	gr/cc	2.740		-
Absorption	%	2.023		Max 3%
The specific gravity of Aggregate	gr/cc	2.570		2.5 – 2.7
Aggregate Content Weight			PB-0204-76 (AASHTO T-19-74/ASTM C-29-71)	
Escape Method	gr/ dm^3	1372.550		-
Stabbing Method	gr/ dm^3	1520.940		-
Shaking Method	gr/ dm^3	1561.963		-
Aggregate Adhesion to Asphalt	%	>95%	SNI 2439:2011	>95%
Aggregate Wear with *Los Angeles* Engine	%	24.626%	SNI 2479:2008	Max 40%
Aggregate Strength Against Impact	%	9.010%	BS:182 Part 112:1990	Max 30%

Table 2. The properties of Rubber Asphalt

Physical Properties of Asphalt	Unit	Value	Specifications	Testing Standards
Penetration	0.1 mm	69.85	≥ 50	SNI 2456:2011
Flash Point	˚C	320	≥ 232	SNI 2433:2011
Burn Point	˚C	> 320	≥ 232	SNI 2433:2011
Ductility	cm	> 100	≥ 100	SNI 2432:2011
Specific Gravity of Asphalt	gram	1.00	≤ 1.00	SNI 2441:2011
Softening Point	˚C	61.5	≥ 52	SNI 2434:2011
Asphalt Stickiness Against Rocks	%	≥ 90	≥ 90	SNI 2434:2011
Weight Loss (Thin Film Oven Test)	%	0.119	≤ 0.8	SNI-06-2440-1991

Table 3. The Properties Asphalt Pen. 60/70

Physical Properties of Asphalt	Unit	Value	Specifications	Testing Standards
Penetration	0.1 mm	62.7	60 – 70	SNI 2456:2011
Flash Point	˚C	258	≥ 232	SNI 2433:2011
Burning Point	˚C	285	≥ 232	SNI 2433:2011
Ductility	cm	> 100	≥ 100	SNI 2432:2011
Specific Gravity of Asphalt	gram	1.025	≥ 1.00	SNI 2441:2011
Softening Point	˚C	54	≥ 48	SNI 2434:2011
Asphalt Stickiness Against Rocks	%	≥ 90	≥ 90	SNI 2434:2011
Weight Loss (Thin Film Oven Test)	%	0.165	≤ 0.8	SNI-06-2440-1991

Based on Table 3, it can be concluded that the results of the inspection of the pen. 60/70 asphalt for all tests has met the specifications according to the Highways General Specifications (Bina Marga 2018 Revision 2) [6].

Determination of The Proportions of Mixed Materials

The method used to determine aggregate content is the mid-section point method, where aggregate weight is obtained by taking the middle value of the HRS-WC specification according to the Circular Letter from Ministers of Public Works and Housing (Pd 07-2019-B) for the specification of hot paved mixtures with asphalt containing natural rubber [17]. The determination of aggregate content can be seen in Table 4 and Figure 2. Based on Table 4 and Figure 2, the percentage of aggregate content in each sieve fraction for the HRS-WC is obtained by the Circular Letter for the specification of hot paved mixtures with asphalt containing natural rubber [20]. The method used to determine theoretical asphalt content is the Department of Settlement and Regional Infrastructure (Depkimpraswil) 2002 method. The theoretical asphalt content used in this test is 7.2%.

Analysis of the Marshall Test

The results of the Marshall Test on HRS-WC can be seen in Table 5 and Table 6.

Table 4. Determination of Aggregate Content

Sieve Size		Aggregate Weight (%)			Specifications
ASTM	mm	Pass (%)	Cumulative retained (%)	Retained (%)	
¾”	19	100	0	0	100
½”	12.5	95	5	5	90 - 100
⅜”	9.5	80	20	15	75 - 85
No. 8	2.36	61	39	19	50 - 72
No. 30	0.600	48	52	13	35 - 60
No. 200	0.075	8	92	40	6 - 10

Pan	-	0	100	8	0

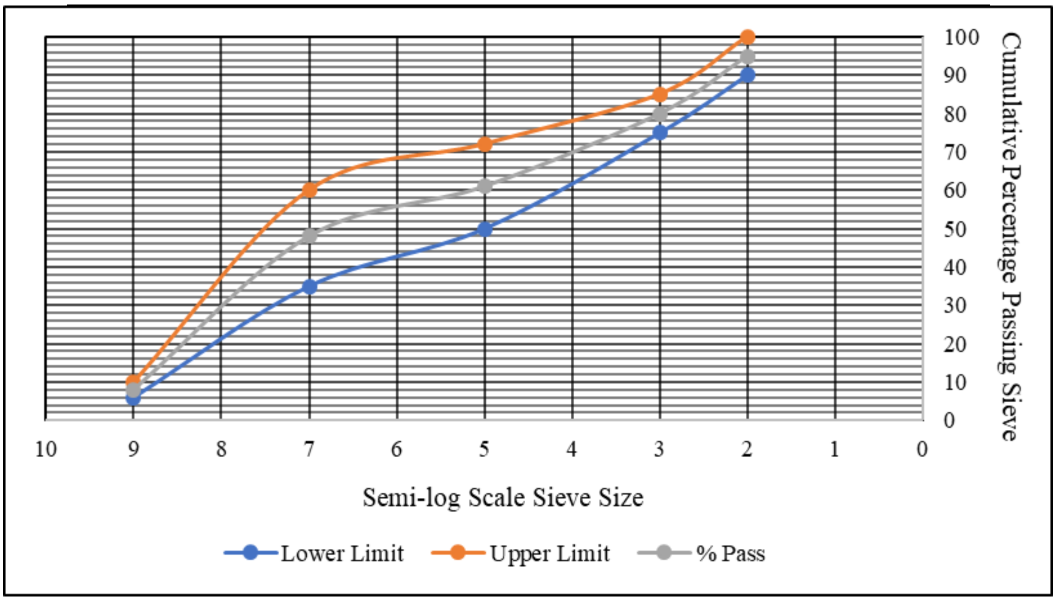

Figure 2. Graph of Aggregate Content

From the results of Marshall calculations in Table 5 and Table 6, a graph of each Marshall characteristic is obtained in Figure 3. Figure 3 shows a graph of the relationship between stability and asphalt content. The graph analysis found that all stability values were included in the specifications, which are ≥ 900 kg for rubber asphalt and ≥ 800 kilograms of penetration 60/70 asphalt [6][21]. Stability value with rubber asphalt and pen. 60/70 asphalt included in the specification has an asphalt content of 6.2% - 8.2%. The stability value of rubber asphalt at the time of OAC (4078.686 kg) is higher than that of the pen—60/70 asphalt (2865.318 kg), where rubber asphalt increased by 42.3%.

Figure 4 shows a graph of the relationship between flow and asphalt content. The graph analysis found that all flow values were included in the specifications used, which are ≥ 3 mm for rubber asphalt and 4-6 mm for pen. 60/70 asphalt [6][22]. Flow value with rubber asphalt and pen. 60/70 asphalt included in the specification has an asphalt content of 6.2% - 8.2%. The flow value of rubber asphalt at the time of OAC (3.257 mm) is lower than that of the pen—60/70 asphalt (5.210 mm), where rubber asphalt decreased by 37.4%.

Figure 5 shows a graph of the relationship between the void filled with bitumen (VFB) and asphalt content. The graph analysis found that all VFB values were included in the specifications, which is ≥ 68% for rubber asphalt and pen. 60/70 asphalt [6][15]. VFB value with rubber asphalt and pen. 60/70 asphalt included in the specification has an asphalt content of 6.2% - 8.2%. The VFB value of rubber asphalt at the time of OAC (71.814%) is lower than the VFB value of the pen—60/70 asphalt (84.207%), where rubber asphalt decreased by 14.7%.

Figure 6 shows a graph of the relationship between the void in the mix (VIM) and asphalt content. The graph analysis found that not all VIM values were included in the specifications, which are 4%-6% for rubber asphalt and 3%-5% for pen. 60/70 asphalt [6][15]. VIM value with rubber asphalt and pen. 60/70 asphalt included in the specification has an asphalt content of 6.36% - 7.9% and 6.4% - 8.2%. The VIM value of rubber asphalt at the time of OAC (6.062%) is higher than the VIM value of the pen—60/70 asphalt (3.070%), where rubber asphalt increased by 97.4%.

Table 5. Marshall Test on HRS-WC Using Rubber Asphalt

Asphalt (%)	VMA (%)		VFB (%)		VIM (%)		Stability (kg)		Flow (mm)		MQ (kg/mm)	
	Rubber Asphalt	**Asphalt pen 60-70**	**Rubber Asphalt**	**Asphalt pen 60-70**	**Rubber Asphalt**	**Asphalt pen 60-70**	**Rubber Asphalt**	**Asphalt pen 60-70**	**Rubber Asphalt**	**Asphalt pen 60-70**	**Rubber Asphalt**	**Asphalt pen 60-70**
6.2	18.60	18.55	74.02	74.27	4.83	4.77	6273.25	2960.39	3.00	3.50	2091.08	845.83
6.2	18.15	16.52	76.23	85.44	4.30	2.41	4803.45	2988.15	3.40	3.30	1412.78	905.50
6.2	17.47	17.72	79.91	78.56	3.51	3.80	4366.47	2628.20	2.80	3.40	1559.45	773.00
Average	**18.07**	**17.60**	**72.74**	**79.42**	**4.22**	**3.66**	**5147.72**	**2858.91**	**3.07**	**3.40**	**1687.77**	**841.44**
6.7	21.64	16.76	66.56	91.27	7.24	1.46	4383.33	2893.30	4.25	6.00	1031.37	482.22
6.7	22.28	18.33	64.08	81.90	8.00	3.32	3598.99	2626.08	3.98	5.30	904.27	495.49
6.7	21.73	16.99	66.19	89.79	7.35	1.73	3742.92	2626.08	2.30	5.30	1627.36	495.49
Average	**21.88**	**17.36**	**65.61**	**87.65**	**7.53**	**2.17**	**3908.42**	**2715.16**	**3.51**	**5.53**	**1187.67**	**491.07**
7.2	22.22	18.96	69.50	84.86	6.78	2.87	3942.00	2575.75	2.75	4.70	1433.45	548.03
7.2	20.03	19.90	79.26	79.94	4.15	3.99	4243.86	2541.07	3.40	5.20	1248.19	488.67
7.2	22.02	18.41	70.30	87.99	6.54	2.21	4133.36	3301.36	3.53	5.55	1170.92	594.84
Average	**21.42**	**19.09**	**73.02**	**84.27**	**5.82**	**3.02**	**4106.41**	**2806.06**	**3.23**	**5.15**	**1284.19**	**543.85**
7.7	20.60	20.18	82.26	84.43	3.66	3.14	3278.82	3256.32	2.57	5.25	1275.81	620.25
7.7	20.60	19.98	82.260	85.47	3.66	2.90	4717.83	2926.21	3.88	5.60	1215.94	522.54
7.7	22.70	20.65	72.69	82.02	6.20	3.71	3344.74	3124.52	3.93	5.50	851.08	568.10
Average	**21.30**	**20.27**	**79.07**	**83.97**	**4.50**	**3.25**	**3780.46**	**3102.35**	**3.46**	**5.45**	**1114.27**	**570.29**
8.2	19.45	21.31	94.68	84.39	1.03	3.33	4121.78	2630.09	3.35	5.40	1230.38	487.05
8.2	21.73	21.32	82.31	84.34	3.84	3.34	3629.54	2359.84	3.84	4.95	945.19	476.74
8.2	20.73	21.54	87.39	83.25	2.61	3.61	4043.27	2831.81	3.57	5.50	1132.57	514.88
Average	**20.64**	**21.39**	**88.13**	**83.99**	**2.50**	**3.43**	**3931.53**	**2607.25**	**3.59**	**5.28**	**1102.72**	**492.89**

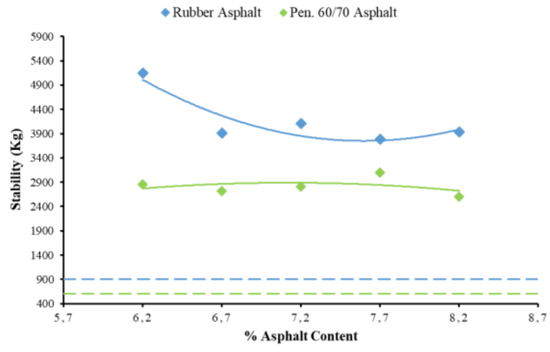

Figure 3. Stability vs Asphalt Content

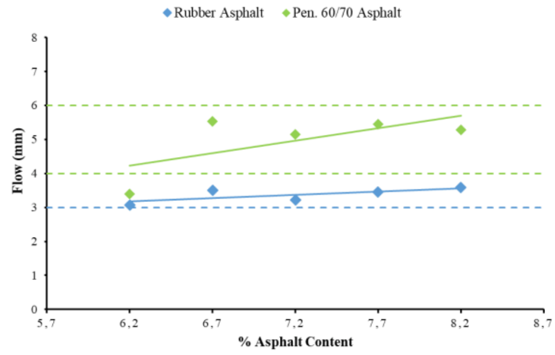

Figure 4. Flow vs. Asphalt Content

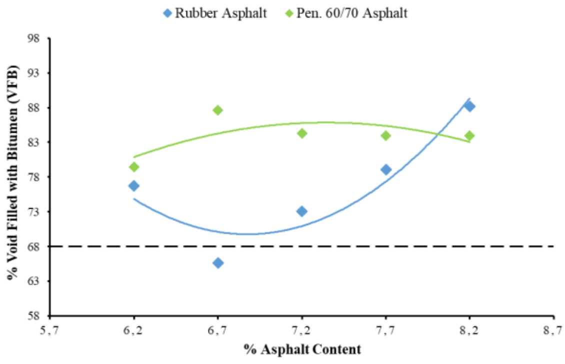

Figure 5. VFB vs. Asphalt Content

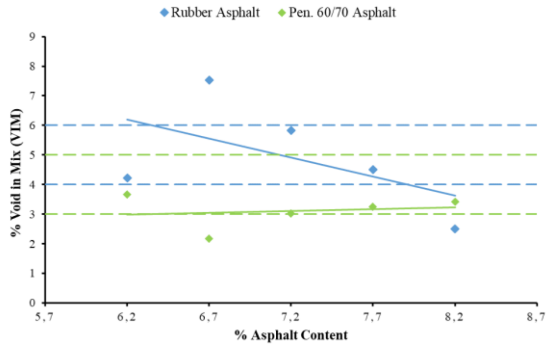

Figure 6. VIM vs. Asphalt Content

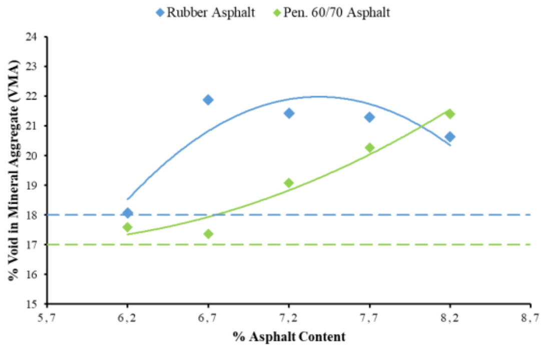

Figure 7. VMA vs. Asphalt Content

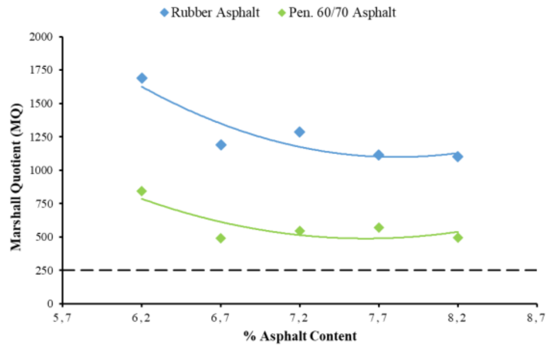

Figure 8. MQ vs. Asphalt Content

Figure 7 shows a graph of the relationship between the void in mineral aggregate (VMA) and asphalt content. The graph analysis found that all VMA values were included in the specifications, which is ≥ 18% for rubber asphalt and ≥ 17% for pen. 60/70 asphalt [6][15]. VMA value with rubber asphalt and pen. 60/70 asphalt included in the specification has an asphalt content of 6.2% - 8.2%. The VMA value of rubber asphalt at the time of OAC (21.487%) is higher than the VMA value of the pen—60/70 asphalt (19.324%), where rubber asphalt increased by 11.1%.

Figure 8 shows a graph of the relationship between the Marshall Quotient (MQ) and asphalt content. The graph analysis found that all MQ values were included in the specifications, which is ≥ 250 kg/mm for a rubber asphalt and pen—60/70 asphalt [6][15]. MQ is rated with rubber asphalt and pen. 60/70 asphalt included in the specification has an asphalt content of 6.2% - 8.2%. The MQ value of rubber asphalt at the time of OAC (1270.676 kg/mm) is higher than the MQ value of the pen—60/70 asphalt (549.136 kg/mm), where rubber asphalt increased by 131.3%.

Based on Figure 9 and Figure 10, the optimum asphalt content can be determined where the optimum asphalt content value is obtained from the average result of the Marshall characteristics included in most specifications. So that the optimum asphalt content is obtained for rubber asphalt of 7.13% and pen. 60/70 asphalt of 7.30%.

Analysis of The Effect of Immersion Time on Marshall Characteristics

The results of the immersion time of the Marshall characteristics can be seen in Table 7. From the results of Marshall calculations in Table 7, a graph of each Marshall characteristic is obtained in Figure 11. Based on Figure 11, the longer the immersion time, the decrease in the stability value of the rubber asphalt mixture. The test found that all stability values were included in the specifications, which are≥ 900 kg [23][24]. This shows that immersion can cause a decrease in the strength of the asphalt mixture because the binding power between asphalt and aggregate is reduced so that the mixture will easily undergo plastic deformation.

Based on Figure 12, it can be concluded that the longer the immersion time, the decrease in the flow value of the rubber asphalt mixture. The test found that all flow values were included in the specifications, which are≥ 3 mm [20][25]. This indicates that the mixture has decreased flow due to immersion. The flow value indicates the degree of stiffness of an asphalt mixture. The low flow value makes the asphalt mixture stiff and brittle so that it will crack easily.

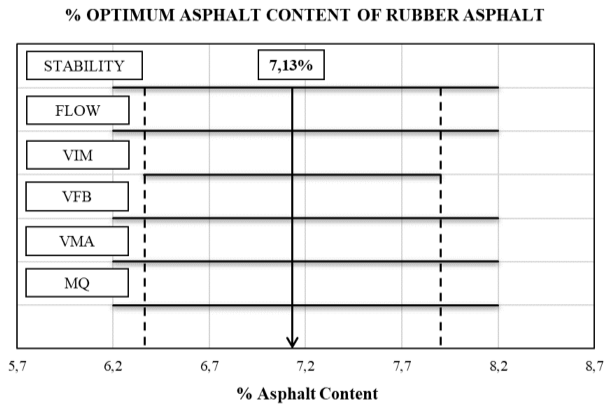

Figure 9. Optimum Asphalt Content of Rubber Asphalt

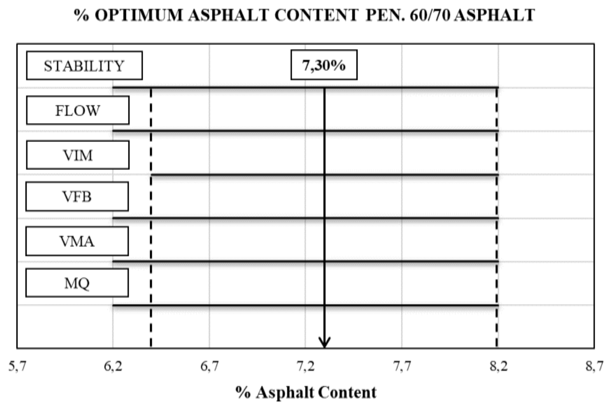

Figure 10. Optimum Asphalt Content of Pen. 60/70 Asphalt

Table 7. Immersion Time Results of Marshall Characteristics

Sample	Time (Hour)	VMA (%)	VFB (%)	VIM (%)	Stability (kg)	*Flow* (mm)	MQ (kg/mm)
IA	0.5	17.883	90.207	1.751	3635.066	3.450	1118.404
IB	0.5	20.100	78.091	4.404	3801.163	3.600	908.845
IC	0.5	19.082	83.306	3.185	4989.026	3.800	826.680
Average	**0.5**	**19.022**	**83.868**	**3.113**	**4141.752**	**3.617**	**951.310**
IIA	24	18.578	86.100	2.582	4117.283	4.100	1053.642
IIB	24	19.120	83.100	3.231	4825.426	3.500	1055.879
IIC	24	19.414	81.543	3.583	2847.695	3.150	1312.902
Average	**24**	**19.037**	**83.581**	**3.132**	**3930.135**	**3.583**	**1140.808**
IIIA	72	18.298	87.716	2.248	3424.496	2.800	1004.215
IIIB	72	19.060	83.425	3.159	3268.837	2.830	1378.693
IIIC	72	20.502	76.176	4.884	3490.337	3.300	904.030
Average	**72**	**19.287**	**82.439**	**3.430**	**3394.556**	**2.977**	**1095.646**
IVA	168	17.627	91.804	1.445	3690.734	3.300	1223.034
IVB	168	18.785	84.932	2.830	2862.860	3.150	1155.066
IVC	168	19.469	81.258	3.649	2976.050	3.600	1057.678
Average	**168**	**18.627**	**85.998**	**2.641**	**3176.548**	**3.350**	**1145.259**

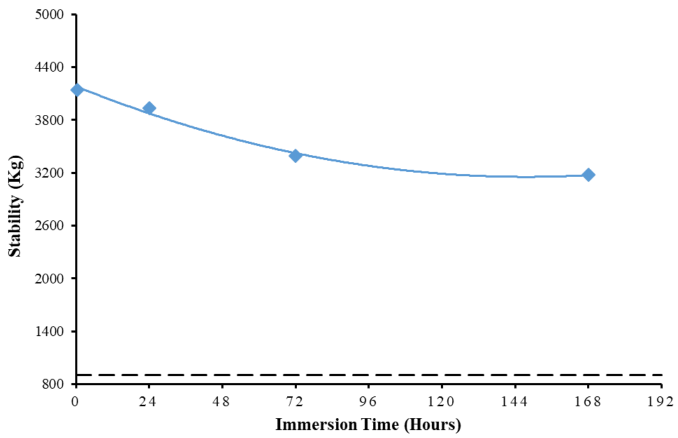

Figure 11. Stability vs Immersion Time

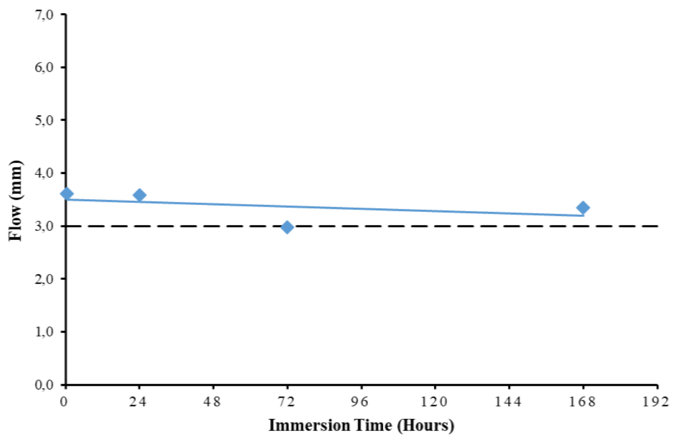

Figure 12. Flow vs Immersion Time

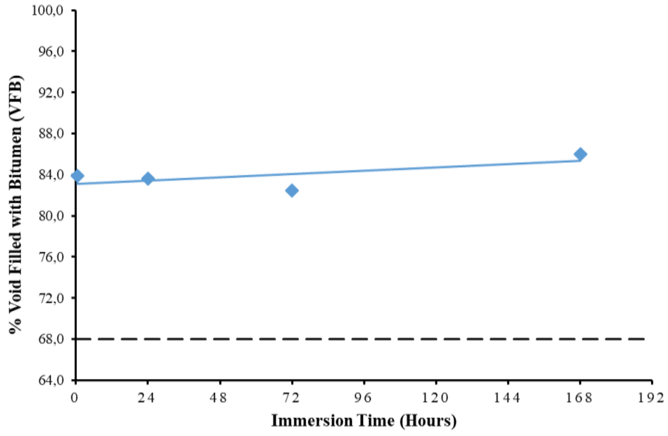

Figure 13. VFB vs Immersion Time

Based on Figure 13, it can be concluded that the longer the immersion time, the more the void filled with bitumen (VFB) value of the rubber asphalt mixture increases. The test found that all VFB values were included in the specifications, which is ≥ 68% [20]. This suggests that immersion can increase the void filled with bitumen. An increase in VFB value characterizes the durability of an asphalt mixture; the more void filled with bitumen, the higher the VFB value, thus making the asphalt mixture more durable.

Based on Figure 14, it can be concluded that the longer the immersion time, the void in the mix (VIM) value of the rubber asphalt mixture decreases. In the test, it was found that there was no VIM value included in the specifications used, which is 4%-6% [26]. The decrease in VIM value due to immersion shows that the voids in the rubber asphalt mixture become small so that the resistance of asphalt to water increases and the oxidation process of the mix can be reduced, which results in asphalt not easily cracking. However, the VIM value is too low and does not meet the specification, causing the void in the mixture to be relatively small and making there not enough space in the mixture so that the asphalt will rise to the surface (bleeding).

Based on Figure 15, it can be concluded that the longer the immersion time, the void in mineral aggregate (VMA) value of the rubber asphalt mixture decreases. In the test, it was obtained that all VMA values were entered into the specifications used, which was≥ 18% [15][16]. This shows that fewer voids in the aggregate, including void-filled air and void-filled bitumen, are ineffective. This causes the precipitation of the mixture to water and air to be lower so that the asphalt mixture will experience bleeding.

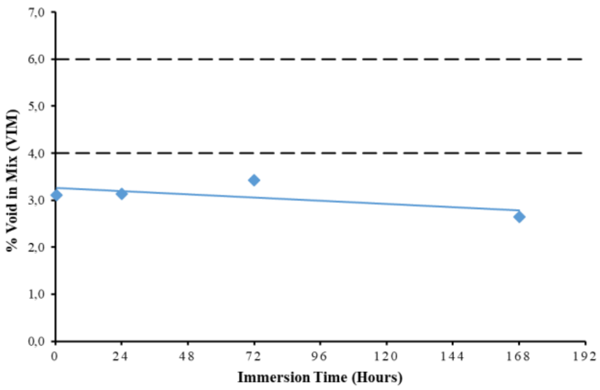

Figure 14. VIM vs Immersion Time

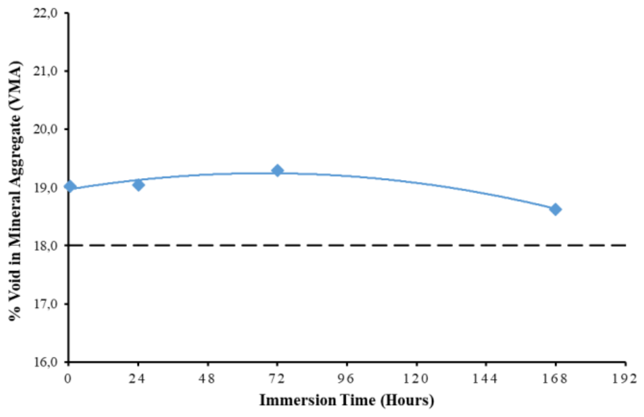

Figure 15. VMA vs Immersion Time

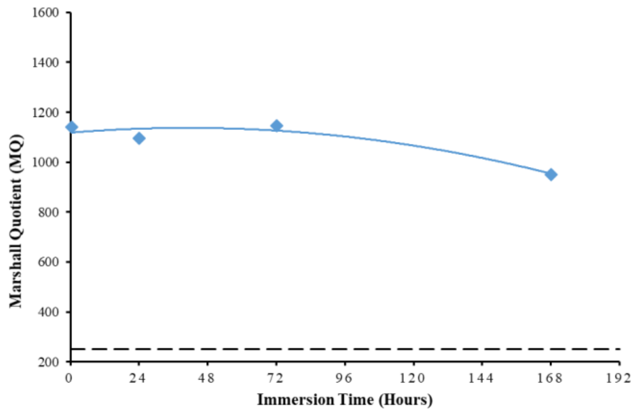

Figure 16. MQ vs Immersion Time

Based on Figure 16, it can be concluded that the longer the immersion time, the more the Marshall quotient (MQ) value of the rubber asphalt mixture decreases. In the test, it was obtained that all MQ values were included in the specifications used, which is ≥ 250 kg/mm [16]. This indicates that the mixture has decreased stability and flow due to immersion. The MQ value indicates the stiffness properties of an asphalt mixture. The low MQ value makes the asphalt mixture elastic and flexible enough to change shape quickly when given a load.

Analysis of the Durability Index

The Residual Strength Index (RSI) value is obtained by comparing the average first stability with the average second stability until the final immersion time. RSI can be calculated using (1) [21].

$$IKS = \frac{S_2}{S_1} x100\% \quad (1)$$

The residual strength index is determined based on (1). The results of the residual strength index value can be seen in Table 8. Based on Table 8, it can be seen that the mixture has decreased stability (loss of strength) due to immersion. This can be seen from the RSI value that the longer the immersion time, the smaller the RSI value. Based on the SE Menteri PUPR 2019 (Pd 07-2019-B) for the specification of hot paved mixtures with asphalt containing natural rubber, the permissible residual strength index value is ≥ 90% [21][26].

Table 8. Residual Strength Index (RSI) on HRS-WC Using Rubber Asphalt

Immersion Time (Hour)	Stability (kg)	Average Stability (kg)	Residual Strength Index / RSI (%)
	3635.066		
0.5	3801.163	4141.752	100.000
	4989.026		
	4117.283		
24	4823.426	3930.135	94.891
	2847.695		
	3424.496		
72	3268.837	3394.556	81.959
	3490.337		
168	3690.734	3176.548	76.696
	2862.860		
	2976.050		

It can be concluded that the residual strength index value that meets the specification is only up to 24 hours of immersion time. This can be caused by the VIM value on the test object durability being too low (relatively degraded) and not included in the specifications used, resulting in insufficient space in the asphalt mixture, which will rise to the surface (bleeding) which causes the durability of the asphalt mixture low rubber.

The total sequential flatness on the durability curve is defined as the First Durability Index (FDI). FDI can be calculated using (2) [21].

$$r = \sum_{i=0}^{n-1} \frac{S_i - S_{i+1}}{t_{i+1} - t_i} \quad (2)$$

The first durability index is determined based on (2). The results of the first durability index value can be seen in Table 9. Based on Table 9, the "r" value is 0.542% and is positive. This indicates that the mixture decreases stability (loss of strength) with increasing immersion time to 168 hours.

An area of average strength loss between the durability curve and the line So =100% is the Second Durability Index (SDI) definition. SDI can be calculated using (3) [17].

$$a = \frac{1}{t_n} \sum_{i=1}^{n} a_i = \frac{1}{2t_n} \sum_{i=0}^{n-1} (S_i - S_{i+1})[2t_n - (t_i + t_{i+1})] \quad (3)$$

The second durability index is determined based on (3). The results of the second durability index value can be seen in Table 10. Based on Table 10, the value of "a" is 8.316% and is positive. This indicates that the mixture decreases stability (loss of strength) with increasing immersion time to 168 hours.

Table 9. First Durability Index (FDI) on HRS-WC Using Rubber Asphalt

Immersion Time (Hour)	Residual Strength Index / RSI (%)	Si-Si+1	ti+1-ti	r (%) = (Si-Si+1 /(ti+1-ti)
0.5	100.000	-	-	-
24	94.891	5.109	23.500	0.217
72	81.959	12.931	48.000	0.269
168	76.696	5.264	96.000	0.055
	Total			0.542

Table 10. Second Durability Index (SDI) on HRS-WC Using Rubber Asphalt

Immersion Time (Hour)	Residual Strength Index / RSI	Si-Si+1	ti+1-ti	2tn-y	a (%) = [1/(2.tn)].x.z	Sa = 100-a
	(%)	x	y	z	a	(%)
0.5	100.000	-	-	-	-	100.000
24	94.891	5.109	24.500	23.500	2.501	97.499
72	81.959	12.931	96.000	48.000	4.310	95.690
168	76.696	5.264	240.000	96.000	1.504	98.496
Total					8.316	

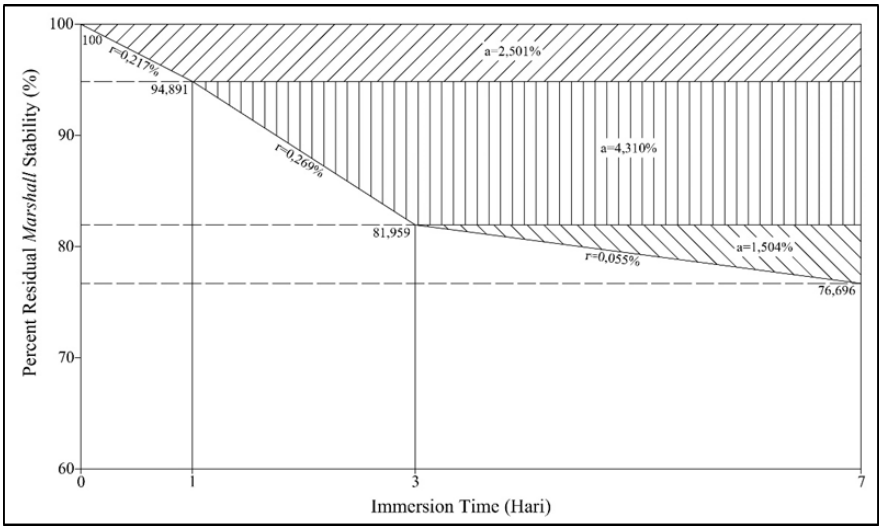

Figure 17. Durability Curve

The value on the durability curve represents the percentage of residual Marshall stability value over the immersion time. The durability curve can be seen in Figure 17. Based on Figure 17, it can be concluded that the residual Marshall stability value decreases with increasing immersion time. This shows that the longer the immersion of the mixture, the durability of the rubber asphalt mixture will reduce (loss of strength). This is caused by water that can damage the structural integrity of the aggregate and asphalt surfaces, and water can cause loss of strength or stiffness of asphalt.

The durability curve describes the magnitude of the strength loss of the mixture per immersion time as indicated by the second durability index (a) in the form of the area of the curve between residual Marshall stability and immersion time. The second largest durability index is found at the 3-day immersion time with a value of 4.310%. The durability curve also describes the flatness of the angle indicated by the first durability index (r). The largest first durability index was found at the 3-day immersion time with a value of 0.269%.

CONCLUSION

The use of rubber asphalt in the HRS-WC obtained an optimum asphalt content of 7.13% with its Marshall characteristics, which is the stability of 4078.686 kg increased by 42.3%, flow 3.257 mm decreased by 37.4%, VFB 71.814% decreased by 14.7%, VIM 6.062% increased by 97.4%, VMA 21.487% increased by 11.1% and MQ 1270.676 kg/mm increased by 131.3%. The durability of the HRS-WC using rubber asphalt relatively decreases with increasing damping time. The RSI value that includes the specification is ≥ 90% only until the immersion time is 24 hours, with a value of 94.891%. The FDI and SDI values are 0.542% and 8.316%. This shows a decrease in stability (loss of strength) in the rubber asphalt mixture up to an immersion time of 168 hours, characterized by a positive durability index. Rubber asphalt in HRS-WC is good enough for pavement because almost all Marshall characteristics were included in the specifications. The stability value of a rubber asphalt mixture is higher than that of pen—60/70 asphalt. However, the level of durability of the rubber asphalt mixture is relatively low because it can only last up to 24 hours of immersion. This is because the void in the mix is relatively small and does not include the specification, which causes the unavailability of sufficient space in the mixture, thereby reducing the durability of the mixture. Therefore, the HRS-WC using rubber asphalt is unsuitable in areas with low groundwater levels or areas that often flood.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support provided by Universitas Andalas.

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